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OPTIMIZATION OF MACHINING MODE UNDER EXTERNAL CYLINDRICAL GRINDING USING T1 TOOL STEEL

Tuan-Linh Nguyen

Fuculty of Mechanical Engineering, Hanoi University of Industry, Hanoi, Vietnam

ABSTRACT

In the grinding process, surface roughness is an very important factor affecting production quality. This paper used empirical research methods to evaluate the influence and optimize the machining mode including cutting mode parameters: Feed rate S_d, rotate speed of workpiece n_w, and cutting depth t. Along with the hardness parameter of the machining material is T1 tool steel which is heat treatment achieving hardness in range 40 to 60 HRC. The goal is to achieve the smallest surface roughness when external cylindrical grinding to shaft details. The achieved results are R_a =0.254261 μm when feed rate S_d = 0.3 mpm, rotation speed of workpiece n_w = 100 rpm, cutting depth t = 0.05 mm, and material hardness = 60 HRC.

KEYWORDS: Surface roughness, Optimization, Machining parameters, Hardness & External cylindrical Grinding

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Original Article

1. INTRODUCTION

Grinding is a final process in manufacturing in which surface roughness is an important indicator determining the quality of the product. The length of the roughness specimen in the grinding surface is 0.8mm. Roughness is measured by the average of roughness R_a. The surface roughness of a grinding element varies from about 0.15 μm to 2.3 μm [5]. Fricker et al., built a roughness prediction model when testing Mild steel when under the influence of grinding wheel and vibration [6]. Chen et el., proposed a simulation model of surface roughness to improve detail quality when grinding depending on the grinding time [7]. Optimizing the cutting mode parameters mentioned when grinding 52100 steel with Hai Duong grindstone, the authors came up with an experimental mathematical model, from this mathematical model found the optimal cutting mode when grinding 52100 steel [8]. In this study, we will analyze and evaluate the influence of some cutting mode parameters and hardness of processed materials on surface roughness when external grinding, thereby finding parameters the main influence to build a mathematical model of surface roughness by experimenting with T1 tool steel and optimizing machining parameters including feed rate S_d, rotate speed of workpiece n_w, cutting depth t and hardness parameter of the machining material is measured on the HRC hardness scale.

2. EXPERIMENTAL SETUP

In this experiment, MEG-120 cylindrical grinding machine is used. The maximum speed of the grinding wheel is at 2000 rpm. The speed of the workpiece is up to 650 rpm. Moving speed of the stepless machine table is from 0.1 to 5 meter per minute (mpm). Grinding wheel dimensions are 400x50x203. 3-grain diamond stone repair tool size is 8.5x40. The used grinding type is center grinding one with flood cooling method. Workpieces are designed with variable diameters of 20, 30, and 40 mm as showed in picture 1. Processing materials are steel T1 tool steel treated

at high temperature with hardness value of 40, 50, and 60HRC, which are measured three times in three measurements on Mitutoyo Surflest SJ-400 roughness meter.

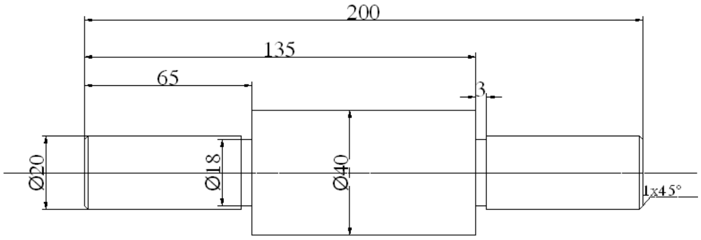

Figure 1: Size of Test Workpiece

Table 1: Steel Brand used for Experiments

Vietnam	Chemical Composition	ASTM
W18Cr4V	C 0.7- 0.8, Si ≤ 0,4, Mn ≤ 0.4, Cr 3.8 – 4.4, V 1-1.4, W 17.5 - 19	T1 tool steel

3. EFFECTIVENESS LEVEL EVALUATION

It is difficult to control the grinding process using entire parameters affected surface roughness. Hence, a specific number of main parameter were determined and evaluated. In order to know which parameters affect the main function, it is necessary to evaluate the influence of the parameters.

To evaluate the influence of the parameters we use Taguchi analysis [4]. Taguchi analysis uses SN signal factors to evaluate results, and to select optimal parameters with small dispersion. This analysis takes into account many factors including noise factors.

Assuming surface roughness is R_a when external cylindrical grinding depends on parameters: cutting mode parameters (feed rate S_d, rotation speed of workpiece n_w, cutting depth t), workpiece parameters (diameter d_w, hardness of HRC). Other not to mention, parameters are considered noise parameters. The relationship function can be built as follows:

$$R_a = f\,(S_d, n_w, t, HRC, d_w) \tag{1}$$

Because these functions depend on many variables, so it is easy to control the cutting process. We evaluate the influence of variables on the target function. This means that only control variables that affect the object function primarily.

3.1. Assessment of the Influence of Material Hardness and Workpiece Diameter on Surface Roughness

The parameters of processed materials are HRC hardness and diameter of d_w.

The experiment was carried out with tempered T1 tool steel to achieve hardness of 40, 50, 60 HRC. The diameter of the test piece with three levels is 20, 30, 40mm. Fixed cutting mode at S_d = 0.5 mpm, n_w = 150 rpm, and t = 0.01mm [1]. An Orthogonal table Taguchi L9 is selected in Table 2:

Table 2: Orthogonal Table Taguchi L9 with Experimental Parameters

No	Hardness HRC	Diameter d_w (mm)	1st $R_{a1}(\mu m)$	2nd $R_{a2}(\mu m)$	3rd $R_{a3}(\mu m)$	$\bar{R}_a$ (mm)
1	40	20	0.36	0.34	0.34	0.35
2	40	30	0.39	0.35	0.36	0.37

3	40	40	0.42	0.39	0.39	0.40
4	50	20	0.50	0.51	0.49	0.50
5	50	30	0.51	0.51	0.52	0.51
6	50	40	0.55	0.54	0.55	0.55
7	60	20	0.59	0.60	0.62	0.60
8	60	30	0.62	0.63	0.62	0.62
9	60	40	0.66	0.65	0.64	0.65

With $SN_i = -10\log(\sum_{u=1}^{N_i} \frac{y_u^2}{N_i})$, so:

Table 3: SN_i Factors is Calculated for Roughness R_a

No	Hardness HRC	Diameter d_w (mm)	R_a
			SN_i
1	40	20	9.1985
2	40	30	8.7052
3	40	40	7.9534
4	50	20	6.0194
5	50	30	5.7916
6	50	40	5.2452
7	60	20	4.3870
8	60	30	4.1053
9	60	40	3.7410

The SN factor is calculated for each indicator and level as follows:

$$SN_{P1,1} = \frac{(SN_1 + SN_2 + SN_3)}{3} \qquad SN_{P1,2} = \frac{(SN_4 + SN_5 + SN_6)}{3}$$

$$SN_{P1,3} = \frac{(SN_7 + SN_8 + SN_9)}{3} \qquad SN_{P2,1} = \frac{(SN_1 + SN_4 + SN_7)}{3}$$

$$SN_{P2,2} = \frac{(SN_2 + SN_5 + SN_8)}{3} \qquad SN_{P2,3} = \frac{(SN_3 + SN_6 + SN_9)}{3}$$

Table 4: Calculated SN Factors for Each Indicator and Level of Hardness and Diameter

Level	R_a	
	SN for Hardness	SN for Diameter
1	8.6190	6.5350
2	5.6854	6.2007
3	4.0778	5.6465
R	**4.5412**	**0.8884**

The results in Table 4 showed that the hardness has more influence than the diameter of the workpiece. Therefore, the material hardness parameter will be the control parameter. With a little influence, the parameter of processing part diameter will be considered as an uncontrolled parameter.

3.2 Assessment of the Influence of Cutting Mode Parameters on Surface Roughness

The studied cutting mode parameters are feed rate S_d, the rotation speed of the workpiece n_w, and the cutting depth t.Change feed rate running along 3 levels: 0.3; 0.4; 0.5 mpm. Change rotation speed of workpiece according to 3 levels: 100; 150; 200 rpm. Change cutting depth according to 3 levels: 0.005; 0.01; 0.02 mm.

Table 5: Orthogonal Table Taguchi L9 with Experimental Parameters

No	S_d (mpm)	n_w (rpm)	t (mm)	1st $R_{a1}(\mu m)$	2nd $R_{a2}(\mu m)$	3rd $R_{a3}(\mu m)$	$\bar{R}_a$ (mm)
1	0.3	100	0.005	0.30	0.33	0.33	0.32
2	0.3	150	0.01	0.33	0.40	0.38	0.37
3	0.3	200	0.02	0.56	0.61	0.59	0.59
4	0.4	100	0.01	0.38	0.39	0.40	0.39
5	0.4	150	0.02	0.49	0.46	0.51	0.49
6	0.4	200	0.005	0.44	0.45	0.42	0.44
7	0.5	100	0.02	0.53	0.55	0.58	0.55
8	0.5	150	0.005	0.36	0.33	0.32	0.34
9	0.5	200	0.01	0.55	0.51	0.56	0.54

Table 6: Calculated SN Factors for Each Indicator and Level of Cutting Mode

Level	R_a		
	SN for S_d	SN for n_w	SN for t
1	0.3867	0.4100	0.3333
2	0.4367	0.3967	0.4033
3	0.4800	0.5233	0.5233
R	0.0933	0.1267	0.1900

As the results of R band in Table 6, it can be seen that the influence of the feed rate S_d, the rotation speed of the workpiece n_w, and the cutting depth t to the surface roughness R_a are nearly equal. Therefore the variables S_d, n_w, t will be the main control variables.

Therefore, it is necessary to build the following mathematical model:

$$R_a = f(S_d, n_w, t, HRC) \quad (2)$$

4. RESULTS AND DISCUSSIONS

4.1 Mathematical Model

Table 7: Experimental Conditions

Parameter	Levels			Interval Variable
	Upper Level +1	Base Level 0	Lower Level -1	
S_d, mpm	0.5	0.4	0.3	0.1
n_w, rpm	200	150	100	50
t, mm	0.025	0.015	0.005	0.01
HRC	60	50	40	10

Table 8: Table of Experimental Parameters with T1 Tool Steel

No	Input Parameters									R_a (μm)
	Code Values					Experimental Values				
	X_0	X_1	X_2	X_3	X_4	S_d	n_w	t	HRC	
1	+1	-1	-1	-1	-1	0.3	100	0.005	40	0.32
2	+1	+1	-1	-1	-1	0.5	100	0.005	40	0.35
3	+1	-1	+1	-1	-1	0.3	200	0.005	40	0.37
4	+1	+1	+1	-1	-1	0.5	200	0.005	40	0.41
5	+1	-1	-1	+1	-1	0.3	100	0.025	40	0.56
6	+1	+1	-1	+1	-1	0.5	100	0.025	40	0.6
7	+1	-1	+1	+1	-1	0.3	200	0.025	40	0.66

8	+1	+1	+1	+1	-1	0.5	200	0.025	40	0.69
9	+1	-1	-1	-1	+1	0.3	100	0.005	60	0.28
10	+1	+1	-1	-1	+1	0.5	100	0.005	60	0.31
11	+1	-1	+1	-1	+1	0.3	200	0.005	60	0.34
12	+1	+1	+1	-1	+1	0.5	200	0.005	60	0.37
13	+1	-1	-1	+1	+1	0.3	100	0.025	60	0.56
14	+1	+1	-1	+1	+1	0.5	100	0.025	60	0.59
15	+1	-1	+1	+1	+1	0.3	200	0.025	60	0.62
16	+1	+1	+1	+1	+1	0.5	200	0.025	60	0.68

By using MATLAB software for programming and calculation, the results are as follows:

$$R_a = 2.2347 S_d^{0.1833} n_w^{0.2572} t^{0.4484} \, HRC^{-0.1860} \quad (3)$$

To assess the appropriateness of the regression equation is to check whether the model obtained correctly describes our experiments or not.

We use Fisher standard to compare:

$$F_{cal} < F_{tab}\,(P, k_1, k_2) \quad (4)$$

In which: $k_1 = N - n - 1$; $k_2 = N(m - 1)$

N: number of experiments ($N = 8$)

n: number of factors affecting the test results ($n = 3$)

m: number of repetitions of the experiment ($m = 3$)

So: $k_1 = 4$; $k_2 = 16$

$$F_{cal} = \frac{S_c^2}{S_r^2} \quad (5)$$

Compatible variance:

$$S_c^2 = \frac{m}{N - n - 1} \sum_{i=1}^{N} (\bar{y}_i - \hat{y}_{tb})^2 \quad (6)$$

Repetitive variance:

$$S_r^2 = \frac{1}{N} \sum_{i=1}^{n} S_i^2 = \frac{1}{N(m - 1)} \sum_{i=1}^{N} \sum_{j=1}^{m} (y_{ij} - \bar{y}_i)^2 \quad (7)$$

In which:

$\hat{y}_i$: Experimental results No. i calculated according to the regression equation

$\bar{y}_i$: The average value of m times experiments in the i^{th} experiment

y_{ij} : the value of the i^{th} experiment in the j^{th} iteration

$\bar{y}_i - \hat{y}_i$: Error between theory and experiment in i^{th} experiment.

Basing on experimental results according to Table 8 and the regression equation (3) we have:

$S_c^2 = 0.1981$; $S_r^2 = 0.1102$

According to the Fisher standard [1]:

$F_{cal} = 1.797 < F_{tab}\ (11, 32, 0.95) = 2.1$

Thus, mathematical models (3) are consistent with reality.

4.2 Optimizing Machining Mode

The program is programmed directly on MATLAB software. Runing the program with the module Optimization Tool/Genetic Algorithm with objective function as eq. (3) and boundary conditions as follows:

Feed Rate: $0.3 \le S_d \le 0.5$

Rotation Speed of workpiece: $100 \le n_w \le 200$

Cutting Depth: $0.005 \le t \le 0.025$

Hardness of machining materials: $40 \le HRC \le 60$

After five runs, we get the following result:

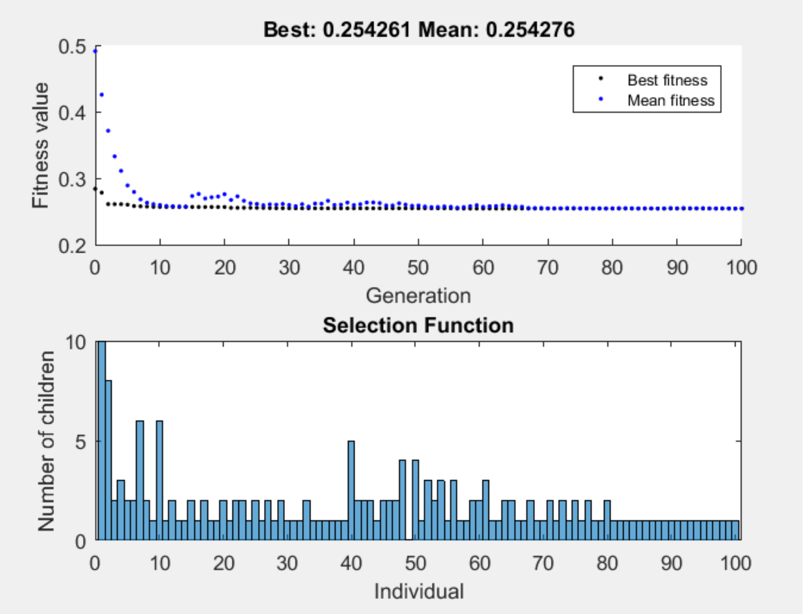

Figure 2: Graph for one Run by Genetic Algorithm.

Table 9: Results of the Program Run with T1 Tool Steel

Variable	S_d (mpm)	n_w (rpm)	t (mm)	HRC
1st run	0.3	100	0.005	59.992
2nd run	0.3	100	0.005	60
3th run	0.3	100	0.005	60
4th run	0.3	100	0.005	60
5th run	0.3	100	0.005	60
Average	**0.3**	**100**	**0.005**	**60**

The results of the program showed the stability of the variable values which changed in a small range. Hence, the

average values were employed in the run lead to a fast convergence speed. However, the rapid convergence rate is also disadvantage of the algorithm. If the convergence is too fast, the reliable information growing in the population will be overlooked and lead to a locally optimal solution. To overcome this disadvantage, we first select the number of generations for the first run and then increase the number of generations until the graph is always a straight line, that is, to achieve the global optimal value.

According to the graphs shown in Figure 2 and Table 9, the smallest surface roughness value can be achieved is R_a = 0.254261 µm when S_d = 0.3 mpm; n_w = 100 rpm; t = 0.005 and material hardness is 60 HRC.

5. CONCLUSIONS

The impact of cutting mode parameters and machining materials was assessed on the roughness of the surface when rounding outside T1 tool steel. The results show that the main parameters affecting surface roughness include feed rate S_d, rotation speed of workpiece n, cutting depth t and material hardness HRC.

A mathematical model for surface roughness was built depending on parameters S_d, n_w, t and HRC when grinding T1 tool steel. This mathematical model allows the control of surface roughness according to parameters S_d, n_w, t when grinding T1 tool steel at each different hardness in the range of 40 to 60 HRC.

The machining mode was optimized under the optimal set of parameters: S_d = 0.3 mpm, n_w = 100 rpm, t = 0.05 mm and material hardness = 60 HRC with the smallest surface roughness achieved as R_a = 0.254261 µm.

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